NAIC-ID(RS)T-0005-96

NATIONAL AIR INTELLIGENCE CENTER

FABRICATION OF MIRRORS WITH SPDT TECHNOLOGY
FOR HIGH-POWERED CO_2 LASERS

by

Weng Zhicheng, Ma Wensheng, et al.

HUMAN TRANSLATION

NAIC-ID(RS)T-0005-96 20 March 1996

MICROFICHE NR: 96C000245

FABRICATION OF MIRRORS WITH SPDT TECHNOLOGY
FOR HIGH-POWERED CO_2 LASERS

By: Weng Zhicheng, Ma Wensheng, et al.

English pages: 8

Source: Chinese Journal of Lasers, Vol. 22, Nr. 1,
Jan 1995; pp. 23-26

Country of origin: China
Translated by: Leo Kanner Associates
F33657-88-D-2188
Requester: NAIC/TATD/Bruce Armstrong
Approved for public release: distribution unlimited.

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

FABRICATION OF MIRRORS WITH SPDT TECHNOLOGY FOR HIGH-POWERED CO_2 LASERS

Weng Zhicheng, Ma Wensheng, Han Rongjiu

State Key Laboratory of Applied Optics
Changchun Institute of Optics and Fine
Mechanics, Chinese Academy of Sciences
Changchun 130022

Shu Baorong, Chen Lanying, and Qian Hongbiu

Shanghai Institute of Optics and Fine Mechanics
Chinese Academy of Sciences
Shanghai 201800

ABSTRACT: This paper describes the optical surface accuracy, reflectance, and laser damage resistance of CO_2 laser mirrors fabricated by means of Single-Point Diamond Turning (SPDT). Mirror lifetime is discussed.

Key Words: single-point diamond turning, CO_2 laser mirrors.

Laser-oriented optical components can be classified into two types: perspective and reflective. Comparatively speaking ,the reflective-type components are believed to be more instrumental in applications requiring high-power and high-power density capabilities. Therefore, developing high-performance reflective mirrors has become a vital subject in advances in laser technology. This paper explores such problems as accuracy of reflective mirrors fabricated with single-point diamond turning technology (hereinafter called SPDT technology), their

reflectance with respect to CO_2 lasers, and their durability.

I. Introduction to SPDT Technology

This is a technology designed to acquired desired surface shapes and surface quality by cutting residual material off a workpiece with diamond as the cutting tool. The material to be machined in this case is nonferrous metal, as well as flat mirrors, spherical mirrors, conical mirrors, cylindrical mirrors, nonspherical mirrors, scanning rotating mirrors, and compound curved mirrors, etc., required in laser machining.

Compared with traditional grinding and polishing for fabricating laser mirrors, SPDT can easily permit designed surface shapes, precision shapes, and surface quality with its advantage of a shorter machining period, which makes it suitable for mass production.

2. Optical Performance of SPDT-Fabricated Mirrors as Applied to CO_2 Lasers

High-powered CO_2 laser mirrors are required to be able to survive damage that may be incurred from irradiation with extremely high-power-density lasers. In other words, their reflective surface must possess high reflectance and low absorptance with respect to lasers. Mirrors fabricated with SPDT show very high reflectance against infrared waveband lasers, which may approach the theoretical limit of reflectance for the given material. However, since the material of such mirrors is nonferrous metals, which are vulnerable to oxidation, with respect to long-term use, normally they need to be coated with a protective film that has ideal chemical stability.

The reflectance of the reflective surface is relative to the roughnesses of the machined surface. Under continuous

irradiation with a laser the mirror temperature may rise and when the temperature rise reaches the critical temperature, the surface may incur damage. This is called the temperature-rise damage theory [1]. It can be expressed with the following formula:

$$\Delta T \sim [(A_{surf} \cdot P_{inc})/K] \times \text{(geometric coefficient)} \quad (1)$$

where A_{surf} is surface absorptance, P_{inc} is incident laser power, and K is the thermal conductivity of the base mirror material.

The performance index of mirror damage (F.M.) is defined as follows:

$$(F.\ M.)_T \sim (T_{dest}/A_{surf}) \cdot K \quad (2)$$

where T_{dest} is the damage-critical temperature.

Another index of mirror performance is optical distortion. Owing to temperature rise, the mirror is subjected to partial distortion regardless of film coating, which primarily happens to its matrix. Since film distortion is ignored because of the thinness of the film, mirror distortion can be roughly expressed as follows:

$$\text{Distortion} \sim \alpha \cdot \Delta T \sim (\alpha \cdot A_{surf} \cdot P_{inc})/K \quad (3)$$

where α is the coefficient of linear expansion for the mirror material.

The optical distortion performance index (F.M.) is defined as:

$$(F.\ M.)_O \sim K/(\alpha \cdot A_{surf}) \quad (4)$$

According to the temperature-rise damage theory, the mirror floor should be made of material with high thermal conductivity and low coefficient of linear expansion. By using SPDT, materials like copper, copper alloys, and aluminum alloys can be easily made into required shapes with relatively smooth surfaces and the microscopic profile of the surfaces thus produced is shown in Fig. 1, which is measured with a Form Talysurf type profilometer.

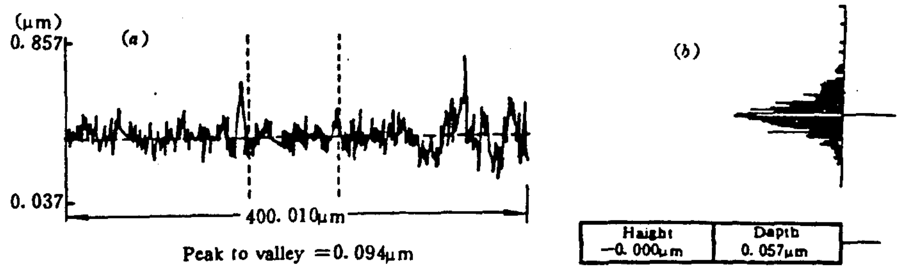

Fig. 1 Profile of a surface produced by SPDT

(a) 2D topogranh of the surface meridian the abscissa. The evaluating length. Evaluation length L_0: 400.010 μm; Mathematics mean value R_a = 0.007 μm; Peak value R_p = 0.057 μm; Root mean square value R_q = 0.009 μm; Valley value R_v = 0.037 μm; Peak to valley value R_t = 0.94 μm; (b) Distribution of amplitude for curve (a). The abscissa is the per centage of the amplitude fluctuation and the ordinade is the amplitude

The face image accuracy of mirrors made with SPDT is less than 0.5μm within the range of OD150mm. Normally, interferograms can be measured with a laser interferometer. Fig. 2 is an interferogram for an off-axis parabolic mirror fabricated with SPDT with a spare-part aperture OD50mm and a parabolic equation Z=1/757.2105chi^2. The measurement principle is shown in Fig. 3.

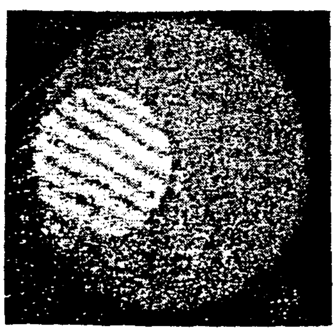

Fig. 2 Interferogram for an off-axis parabola mirror fabricated by SPDT

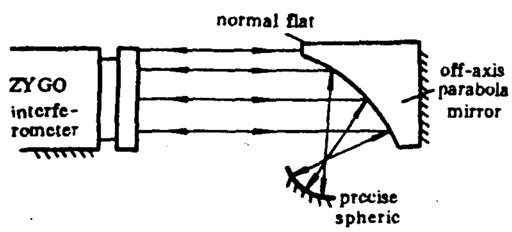

Fig. 3 Principle map for the measurement of the off-axis paraboia mirror

By using a statistical method, H. Davies derived an expression for the mirror-surface reflectance R_0, as follows:

$$R_s = R_0 \cdot \exp[-(4\pi\delta/\lambda)^2] \qquad (5)$$

where R_0 is the reflectance of the completely smooth surface of the material; ¢ is the mean-square-root of the surface roughness; and lambda is the wavelength of the incident light.

The conditions required for Eq. (5) are: 1) $\delta \ll \lambda$; and 2) Surface fluctuation amplitude distribution is a gaussian distribution with the neutral axis of mean value as its center. The mean-square-root value of curve (a) in Fig. 1 is equal to 0.009µm, which is much smaller than lambda=10.65µm. Fig. 1(b) indicates that the fluctuation amplitude is gaussian in its distribution with the line of 0.057µm in depth (i.e., the neutral axis line of mean value) as its center, from which the face cut with SPDT can be calculated according to Eq. (5), as follows:

$$R_s = R_0 \cdot [1 - (4\pi\delta/\lambda)^2] \qquad (6)$$

Fig. 4 is a schematic diagram showing how TIS [total integrated surface] is generated on a rough surface. When ¢=0.009µm, $R_s=R_o$x0.999, ¢=0.040µm, $R_s=R_o$x0.9994, and ¢=0.040µm, $R_s=R_o$x0.9977.

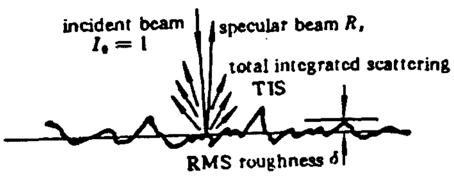

Fig. 4 Schematic drawing of total integrated scattering by a rough surface

Then it can be concluded that when the mirror machined with SPDT is applied to a CO_2 laser and its mean-square-root surface roughness ¢ reaches 0.04µm, the surface discussed is already quite smooth. While the major factor that determines its reflectance is R_o, this quantity varies with different materials and different surface conditions.

Table 1 Laser damage text data for different specular mirrors

SN	SM	RSPDTS	Reflective index (%)			LDTH	IT	TS	FS
		(μm)	SPDTS	GC	AF	(W/cm², 10.6μm)	(min)	(℃)	
L_1	LY12	0.011	97.12	98.92		$>1.4\times10^5$	12	269	Damage-free
L_2	LY12	0.008	97.22		97.06	1×10^5	1	105	Point microfusion
L_4	LY12	0.012	97.37			1×10^5	3	204	Point fusion
L_6	LY12	0.013	97.33		97.24	1×10^5	2	230	Point microfusion
P_1	HP_{659-1}	0.008	97.28	98.97		$>1\times10^5$	12	183	Damage-free
P_2	HP_{659-1}	0.010	97.35		97.38	1×10^5	5	290	Point microfusion
P_4	HP_{659-1}	0.010	97.36			1×10^5	2	161	Point microfusion
P_{15}	HP_{659-1}	0.021	97.72			1×10^5	3	202	Point fusion
P_{20}	HP_{659-1}	0.059	96.72			1×10^5	4	227	Surface oxidization
H_1	H62	0.010	97.55	98.96		1×10^5	6	166	Point fusion
H_2	H62	0.010	97.39		97.50	1×10^5	3	223	Point microfusion
H_3	H62	0.009	97.40			1×10^5	4	165	Point fusion
T_1	Oxygen-free coppr	0.007	99.34	99.06		$>1.4\times10^5$	12	117	no variation
T_2	Oxygen-free coppr	0.008	99.35		99.16	$>1.4\times10^5$	12	134	no variation
T_4	Oxygen-free coppr	0.011	99.14			1×10^5	12	138	gradual oxidizing
1*	Oxygen-free coppr				98.7 routine machining	1×10^5	10	173	surface oxidization
2*	H62			96.5 chemical plating		1×10^5	3	320	Point microfusion

SN: Sample number; SM: Sample material; RSPDTS: Roughness of SPDT surface; SPDTS: SPDT surface; GC: Gold-coating; AF: Antiabrasion film; LDT: Laser damage threshold; IT: Irradiation time; TS: Temperature of substrate; FS: Final state

On an MSG-325 machine tool, using SPDT, we produced a set of mirror lenses with OD35mm in size, 4mm in thickness, through which we measured their surface roughness, absolute reflectance, and reflectance of gold or protecting film coating, as well as experimented with the laser-damage resistance capability without any wind or water cooling conditions. The results of the experiment are listed in Table 1.

The test pieces outlined in Table 1 were made of cold-rolled rods available commercially. The SPDT surface roughness was measured with a Form Talysurf profilometer sold by Taylar Hobson Company, and the gold coating and the oxide protective film coating were produced with a steaming method. An experiment with laser resistance capability was conducted at the Laser Applications Center under the Shanghai Institute of Optics and

Fine Mechanics, Chinese Academy of Sciences. To accelerate the process of checking the laser damage to the mirror surface, the measurements were carried out under direction irradiation with a 2kW and a 5kW laser beam, without water and wind cooling conditions. The experiment showed the following results:

1) materials, including copper, brass, and aluminum alloys, can all be made with SPDT into smooth lasers with respect to lasers and a wavelength lambda=10.6μm. The roughness of the machined surface is relative only to the equipment used and the turning parameter.

2) In light of the reflectance of a reflective surface in different states (lambda=10.6μm), the SPDT surface of oxygen-free copper is the highest, followed by the gold-coated surface, and then by the SPDT surface of brass and aluminum alloys, whereas the reflectance of a surface with an oxide protective film coating relies on that of the matrix surface and shows a decrease of about 0.5%.

3) Since aluminum has a low density and its blank preparation costs are low, it therefore best serves the needs of SPDT processing. Consequently, aluminum alloys or brass can be considered as mirror material for application under irradiation with a laser with power density less than or equal to $10^5 W/cm^2$, while oxygen-free copper can be selected when the power density $>10^5 W/cm^2$, and

4) The laser damage resistance capability of test pieces listed in Table 1 is likely to increase enormously under favorable cooling conditions.

3. Durability of Mirrors Made with SPDT

As discussed in section 2, mirror damage results from heat. The surface roughness R of mirrors fabricated with SPDT can be less than 0.04μm in any case with reflectance R_q. Unlike the traditional grinding and polishing approach, SPDT shows no sand fillings with its R_s being proportional to R_o of the material of

the mirror in question. Nevertheless, the complicated environments under which the mirror is used, such as debris and smoke as contaminants, can cause its reflective surface to undergo a qualitative change, i.e., the reflectance may deteriorate with the degree of contamination and in that case, the surface is no longer a surface machined with SPDT. The experiment with laser resistance capability has already demonstrated that the test lens with no coating can resist a high-power-density laser without being damaged for a certain period of time. However, damage can develop at very fast rates, starting with surface deterioration. It is merely a matter of an instant that damage goes from point microfusion to burnthrough. It is therefore believed that mirror durability is determined primarily by the state under which a particular mirror is applied. Structure designers and site users need to stress strongly that the key to extending mirror durability is continually keeping mirror surfaces clean when in use.

Acknowledgments. Our thanks to Shao Guiying, vice research fellow from the State Quality Test Center of Optical and Machined Products for her efforts in the reflectance test, and to Chu Guojiang and Yu Zhiheng from the Changchun Institute of Optics and Fine Mechanics for their enthusiasm in preparing the film coatings. Participants involved in this project also included Yu Jingchi, Huang Wei, and Wang Shurong from the Changchun Institute of Optics and Fine Mechanics, and Hu Wenfu, Wu Huaiying, and Chai Hongjun from the Shanghai Institute of Optics and Fine Mechanics.

The paper was received for publication on March 8, 1994. The revised paper was received on April 25, 1994.

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION	MICROFICHE
B085 DIA/RTS-2FI	1
C509 BALLOC509 BALLISTIC RES LAB	1
C510 R&T LABS/AVEADCOM	1
C513 ARRADCOM	1
C535 AVRADCOM/TSARCOM	1
C539 TRASANA	1
Q592 FSTC	4
Q619 MSIC REDSTONE	1
Q008 NTIC	1
Q043 AFMIC-IS	1
E404 AEDC/DOF	1
E410 AFDTC/IN	1
E429 SD/IND	1
P005 DOE/ISA/DDI	1
1051 AFIT/LDE	1
P090 NSA/CDB	1

Microfiche Nbr: FTD96C000245

NAIC-ID(RS)T-0005-96